NATIONAL RADAR REFLECTIVITY MOSAIC FROM WSR-88D RADAR CODED MESSAGES

David H. Kitzmiller
Techniques Development Laboratory
Office of Systems Development
National Weather Service
Silver Spring, Maryland

David L. Keller
Research and Data Systems Corporation
Greenbelt, Maryland;
General Sciences Corporation
Beltsville, Maryland

1. INTRODUCTION

Weather surveillance radar is used extensively in short-range forecasting operations. Even for local forecasting operations, it is highly desirable to view the observations of several radars simultaneously, in order to monitor the development and movement of synoptic-scale systems or to get the best possible observations of small-scale features which are distant from the radar nearest the forecast office.

The product described below is a digital radar reflectivity mosaic for the contiguous United States based on data contained in Radar Coded Messages. It features seven reflectivity levels, from < 15 dBZ to ≥ 55 dBZ, and indicators for missing coverage. Its mesh length is approximately 10 km and it is produced twice per hour. Automated quality-control algorithms have been applied to remove most nonprecipitation features. The mosaic is disseminated in GRIB format under WMO bulletin header HAXA00 KWBC.

The mosaic is intended as a tool for monitoring the development and movement of synoptic-scale and meso-α scale features. Because of its coarse horizontal and temporal resolution and limited dynamic range, it is not suited to hydrologic applications or to local warning operations. The automated quality-control algorithms do not successfully identify all nonprecipitation echoes, though features such as anomalous propagation and returns from birds that sometimes enter the mosaic can usually be identified visually by forecasters with even limited experience. In rare instances the algorithms may remove actual precipitation echoes.

2. HISTORY

The National Weather Service (NWS) implemented some radar mosaicking operations as early as the 1960's. These operations were based on collection and compositing of manually-digitized information transmitted from individual radar sites (Sadowski, 1979; NWS 1980; Departments of Commerce and Defense 1980). The manual radar observations (ROB's) included descriptions of echo regions, convective-scale phenomena (e.g. hook echoes, line-echo wave patterns), and radar-relative echo velocities. Nonhydrometeorological echoes due to ground clutter (GC), anomalous propagation (AP), or aerial targets such as aircraft, insect swarms or birds were eliminated by the operator based on other data and personal experience. A 40-km national Manually-Digitized Radar (MDR) mosaic was also created by compositing local gridded data reported by radar operators.

With the deployment of the WSR-88D network, the ROB was replaced by the automatically-produced Radar Coded Message (RCM). The RCM contains the local portion of a national 10-km reflectivity mosaic, a description of convective echoes including maximum reflectivity, echo tops and mesocyclone phenomena, and the local Velocity-Azimuth Display Wind Profile (Office of the Federal Coordinator for Meteorology 1991). This technical procedures bulletin describes the method used to create a national reflectivity mosaic from RCM’s by a purely automated process.

The first national program for the production of a national reflectivity mosaic from RCM’s was implemented within the NWS National Centers for Environmental prediction, at the Aviation Weather Center (Lewis and Mosher 1992; Cope 1994); the mosaicking operation was instituted primarily to support the automated generation of text radar observations, and the mosaic itself was not disseminated operationally. The AWC operation relied on communications systems and proprietary system software due to be eliminated with the introduction of the Advanced Weather Interactive Processing System (AWIPS). Accordingly, it was decided to rehost the program within NWS Telecommunications Gateway facility. More complete descriptions of the mosaic procedure is contained in Lewis and Mosher (1992) and in Keller and Kitzmiller (2000).

3. INPUT DATA

Several data streams are utilized in constructing the output radar products and analyzing them to remove echoes that are likely due to ground clutter (GC), anomalous propagation (AP), or aerial nonprecipitation targets such birds, aircraft, and insects.

a. Radar Coded Messages (RCM's)

The RCM (OFCM 1991) contains a coded text description of the local portion of the national reflectivity mosaic, and coded descriptions of convective storm cells with the local radar umbrella. A line of text contains the starting row and column position of a row of nonzero reflectivity values (0-8) observed along rows within the grid. These reflectivities are derived from the Digital Hybrid Scan (DHS) reflectivity array, which is also used to derive precipitation accumulation estimates.

The DHS incorporates quality control procedures designed to reduce or eliminate GC, AP, and spurious 'shot noise' (Fulton et al. 1998). However, significant nonprecipitation features sometimes remain in the RCM's, with AP appearing on occasion and returns from biological targets (birds and insects) being common. Comparison of unedited and manually-edited mosaics showed that almost 25-30% of echo features were not due to precipitation in summer and early autumn, while about 10% of all echoes were not due to precipitation in winter. This contamination makes some further quality control (QC) necessary.

The RCMs are produced twice per hour, roughly in the intervals 00:10-00:20 and 00:45-00:55, and are centrally collected on a file server at NWS headquarters.

b. Infrared satellite

Satellite observations in the 11-μ channel at 4-km resolution are analyzed to determine the coldest value within each RCM grid box. Data from both GOES-East and GOES-West satellites are utilized. As described below, it is assumed that precipitation can occur only when lightning is observed or if the cloud-top temperature indicates a cloud that is optically 2 km thick; thus only grid boxes in which the satellite-derived temperature is lower than the environmental temperature at 2 km above the lifting condensation level are assumed to support precipitation echoes.

c. Numerical weather prediction model forecasts

Temperature and height forecasts from the Eta numerical weather prediction model are used to estimate the lifting condensation level (LCL) and the environmental temperature above the LCL. This information is used in conjunction with satellite data to infer the probability that radar echoes actually represent precipitating clouds.

d. Lightning

Cloud-to-ground (CG) lightning strikes observations are used to confirm the presence of precipitating echoes. Strikes within a time window of 15 minutes about the nominal radar collection time are employed in QC procedures.

4. THE RADAR COMPOSITE

The mosaic is projected on a polar stereographic grid with the following characteristics:

Orientation: 105°W (255°E)
Reference latitude: 60°N
Mesh length at reference latitude: 11906.25 m
Lower-left corner position: 119.036°W, 23.097°N
Upper-right corner position: 58.025°W, 45.317°N
Number of rows: 360
Number of columns: 460

This grid is coaligned with the MDR grid and the Hydrologic Research and Applications Program (HRAP) grid, which have reference mesh lengths of 47625 m and 4762.5 m, respectively.

Note that our convention is that grid position (1,1) is at the lower-left corner of the lower-left box; thus continuous grid position values ≥ 1 and < 2 are within box 1, position values between 2 and 3 are within box 2, etc.

The reflectivity data within the grid describe the largest value observed within the box. The reflectivity values are coded as follows:

0: < 15 dBZ	4: 45-49 dBZ
1: 15-29 dBZ	5: 50-54 dBZ
2: 30-39 dBZ	6: ≥ 55 dBZ
3: 40-44 dBZ	7: No coverage or degraded coverage.

A value of 7 is placed in grid boxes that lack coverage from any radar, due to permanent gaps in network coverage, temporary gaps due to nonreporting radars, or subregions within radar umbrellas that are seriously occulted by terrain features. Note that the RCM's themselves contain values of 7 and 8 to describe echoes beyond 230 km from the radar; these are essentially indeterminate values and no attempt has been made to include them in the mosaic.

For grid boxes covered by multiple radars, the highest observed reflectivity value is placed in the final composite. While it is sometimes considered desirable to assign the reflectivity observed by the closest radar to the box, the strategy we chose is the simplest to apply operationally, and ensures continuous spatial coverage when some radars are temporarily nonreporting, or when radar units are moved or installed. The ‘highest observed reflectivity’ method may sometimes introduce features such as elevated hail cores into the composite while the ‘nearest radar’ approach would not; however such features are of concern mainly when the aim is to produce rainfall estimates from the data. The primary purpose of this composite is to provide a synoptic overview, with an emphasis on identifying the location and approximate intensity of precipitation. It is not intended for rainfall estimation, since the input reflectivity field has insufficient spatial resolution, temporal resolution, and dynamic range for such a purpose.

Sample reflectivity composites appear in Fig. 1 (national view) and Fig. 2 (regional view). The composites are produced twice per hour, and are available at about 00:05 (for RCMs from 00:45) and 00:35 (for RCMs from 00:15).

5. QUALITY CONTROL

As noted above, nonprecipitation echoes are often present in RCM’s. In order to eliminate GC, AP, biological targets, and other nonprecipitation echoes from the composite, RCM grid boxes with nonzero echo levels are flagged for deletion unless other sources indicate the potential for precipitation, and unless there is spatial continuity in the echo field. Since the radar data are available only in a degraded spatial resolution and dynamic range, more sophisticated QC recognition techniques cannot be applied.

Precipitation is presumed to be possible within a grid box if:

(a) satellite observations and the Eta model forecast sounding for the area indicate that the satellite temperature is no warmer than the environmental temperature at a level 2 km above the lifting condensation level of a surface parcel. This condition is, in effect, requiring that a cloud with a depth of at least 2 km is coincident with the radar echo (Lewis and Mosher 1992);

or

(b) one or more lightning strikes have been observed within the grid box near the radar observation time.

In practice, we adopted a convention that the surface parcel has the relative humidity of the lowest 60-mb layer as indicated by the model. A shallow humid layer, such as often exists at night, tends to result in an unrealistically low LCL value within atmospheric columns that are dry aloft. This convention raises the LCL to a more realistic value. If the satellite imagery and LCL field indicate possible precipitation for one grid box, precipitation is also deemed possible in neighboring boxes.

The Eta model data is available at a vertical resolution of 50 mb, and a horizontal resolution of approximately 80 km. The following conventions are used in determining which model run and forecast projections are employed:

For 0000-0359 UTC: 12-h projection from model run at 1200 UTC;
For 0400-0859 UTC: 6-h projection from model run at 0000 UTC;
For 0900-1559 UTC: 12-h projection from model run at 0000 UTC;
For 1600-2059 UTC: 6-h projection from model run at 1200 UTC;
For 2100-2359 UTC: 12-h projection from model run at 1200 UTC;

After the satellite/lightning criteria have been satisfied, a 'shot noise' filter is applied to the remaining echoes. If a reflectivity value is 3 or more levels higher than those in the surrounding 8 gridpoints, then it is flagged for deletion. For example, a value of 3 that is completely surrounded with '0' will be deleted, as will a value of '6' surrounded by values of 3 or less.

Further details of the automated image editing procedure are described in Keller and Kitzmiller (2000).

6. INDICATIONS OF MISSING RADAR COVERAGE

Though most places in the U.S. are within 230 km of one or more WSR-88D's, there are coverage gaps over sparsely-populated portions of the Great Basin and the Southwest. Also, some places within 230 km of only one radar are essentially uncovered because of beam blockage by terrain features. In addition to such permanent coverage gaps, temporary gaps appear in the vicinity of nonfunctioning or nonreporting radars.

Examination of echo climatologies showed that occultation seriously affects some umbrellas in the western U.S.. The relative frequency of echoes $\geq$ 15 dBZ during the period 1 October - 31 December 1997 and 1 September - 31 October 1998 appears in Fig. 3. Occulted areas appear as clear wedges near the boundaries of individual umbrellas, mostly near the national borders (note particularly the umbrellas surrounding El Paso, Texas; Tuscon, Arizona; and Portland, Oregon). In occulted areas, only a few echoes are ever detected. Because this climatology was derived from RCM mosaics, most occulted areas within the interior of the country are covered by neighboring radars. Occultation gaps generally appear only at some distance from the radar, because at close ranges reflectivity from the second or third antenna elevations is used to approximate the value at the lowest angle when the lowest beam is blocked. These higher angles often overshoot precipitation at greater ranges.

To determine regions likely to be affected by terrain blockage, we obtained occultation maps for each site from the NWS Operational Support Facility. The maps indicate the percentage of the radar beam that is blocked by terrain as a function of azimuth and range for the each of the lowest four antenna elevation angles. These four scans are used to construct the Digital Hybrid Scan (DHS) reflectivity product, from which precipitation accumulation and the RCM reflectivity are derived.

By comparing these maps to the echo climatology we developed a convention for determining blockage in the RCM grid. A box is considered blocked with respect to a radar if either condition (a) or (b) apply:

(a) the box is centered more than 100 km from the radar and more than 50% of the azimuth/range bins over the box are more than 55% occulted at the lowest antenna elevation;

(b) more than 33% of the azimuth/range bins over the box are more than 55% occulted at both the first and second antenna elevation angles.

These conventions yield good agreement with the echo climatologies described above. The blockage pattern surrounding each radar is applied to the local section of the mosaic when the radar's observations are incorporated. If the reflectivity level for a box is zero and the occultation map indicates that the box is blocked, a missing indicator is stored there. The indicator is cleared if another radar's observations cover the box.

Mosaic grid boxes left uncovered for any reason are described by a reflectivity code of 7. Note that this is different from the convention within RCM's, where 7 and 8 describe echoes beyond 230 km from the reporting radar.

In practice, a file containing the portion of the national RCM grid covered by each radar has been created. When individual RCM’s are composited, this file is used to determine which subsection of the national grid is covered by the local radar umbrella. Occulted areas within the local umbrella remain uncovered in the national grid unless another radar is present to complete the coverage.

In Fig. 1, coverage gaps beyond 230 km from any radar exist over extreme northeast Arizona and northwest New Mexico; gaps due to occultation are evident to the west of Portland, Oregon and south of Tuscon, Arizona; a temporary coverage gap due to nonreporting radars appears over Nebraska and South Dakota.

7. FUTURE WORK

Work is underway to refine the QC algorithms by in several ways. A set of manually-edited and corresponding unedited radar mosaics has been collected for use in developing and objectively testing QC procedures. We are testing algorithms developed by statistically relating satellite temperature, K index, layer-mean relative humidity, and lifted index with the outcome of editing decisions. Results suggest that a decision index based on a linear combination of these variables accurately duplicates the results of manual editing. We have also found that echoes observed by two or more radars are almost certain to be accepted as precipitation, and plan to use that criterion in future. As noted above, we are also attempting to automatically identify returns from biological targets by measuring the size, shape, location, and intensity spectrum of echo patterns near radar sites.

Efforts are now underway to create reflectivity and vertically-integrated liquid (VIL) from other WSR-88D products. These mosaics will feature 16 intensity levels and can be generated at 2- and 4-km resolution several times per hour.

8. ACKNOWLEDGMENTS

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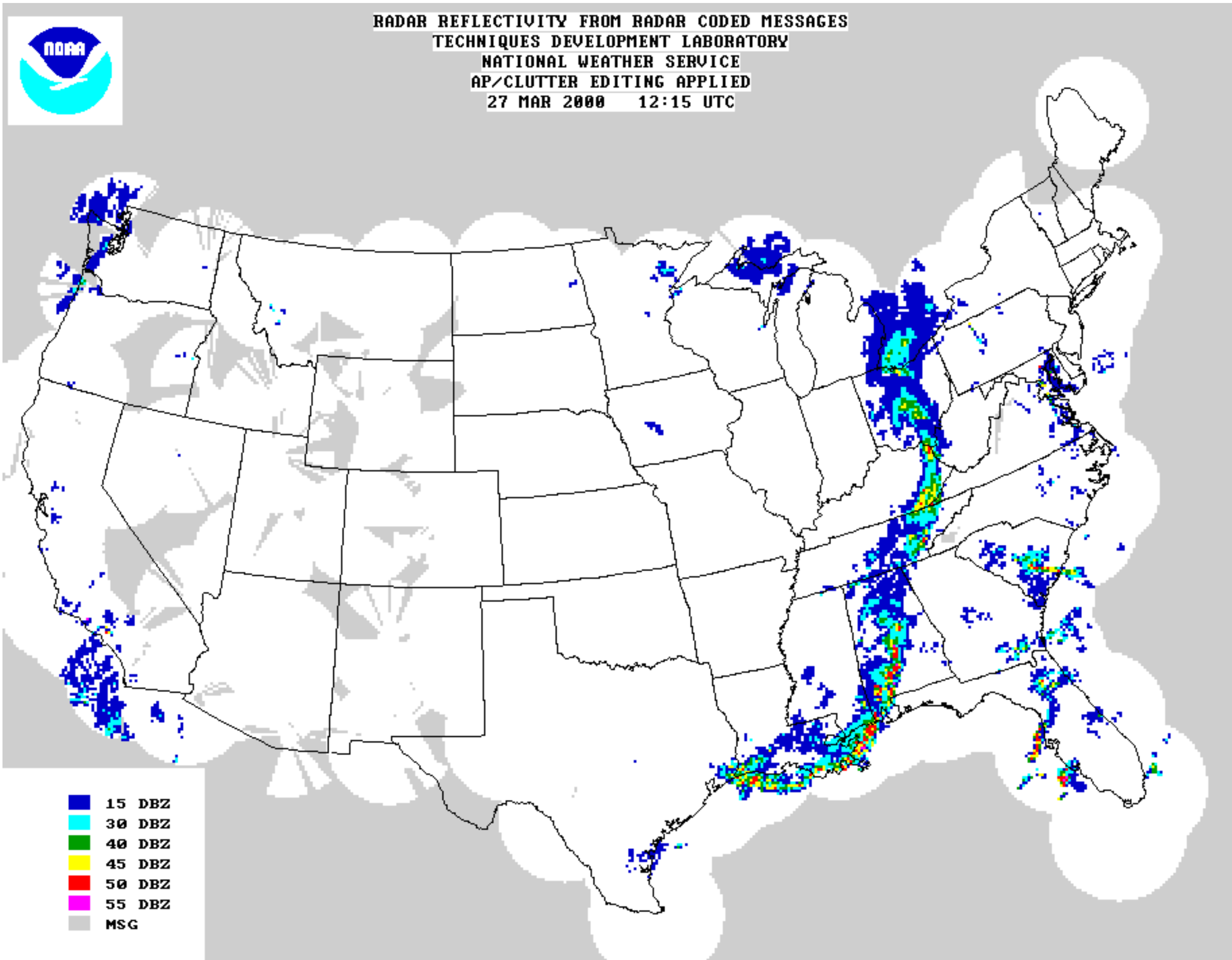

Figure 1. National 10-km radar composite from Radar Coded Messages, for 1215 UTC, 27 March 2000. Blank areas indicate reflectivity < 15 dBZ, light gray shading indicates no radar coverage. Echo intensity within precipitation areas is described in the legend at lower left.

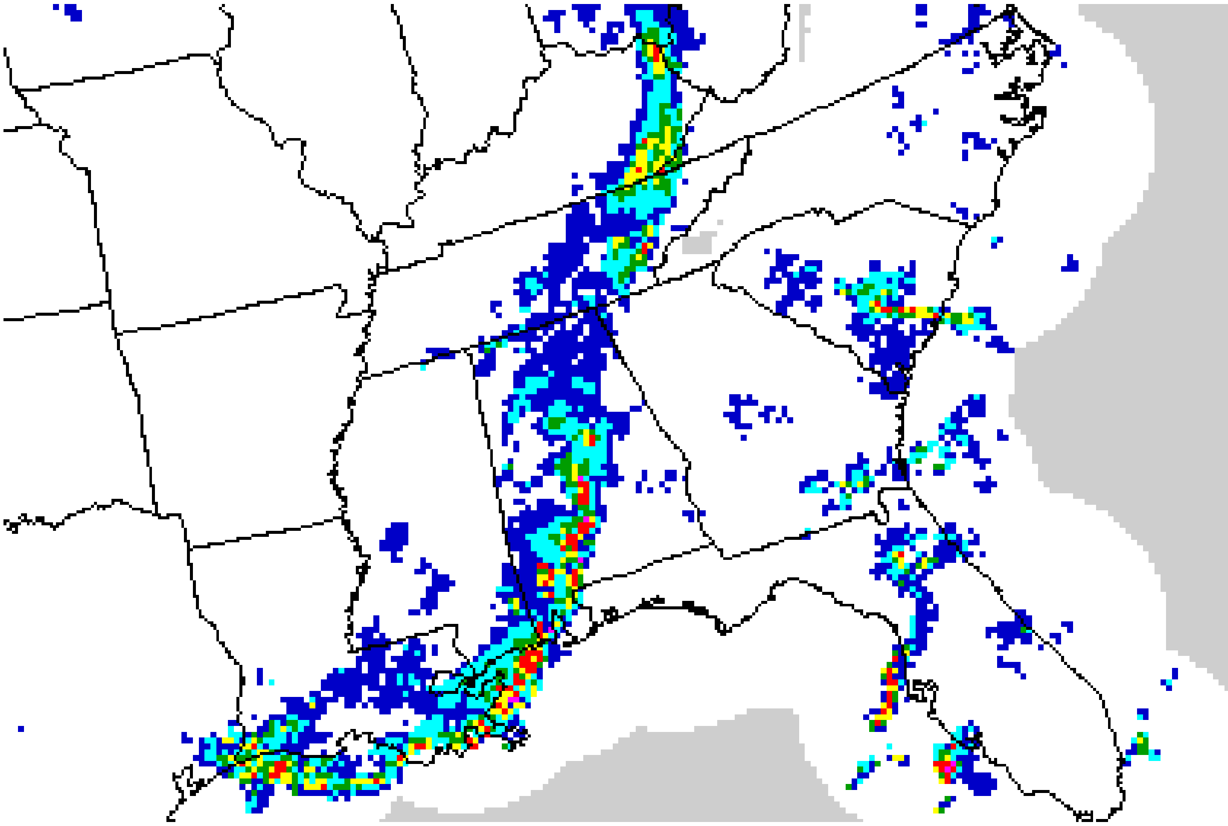

Figure 2. As in Fig. 1, except for subsection covering the southeastern United States.

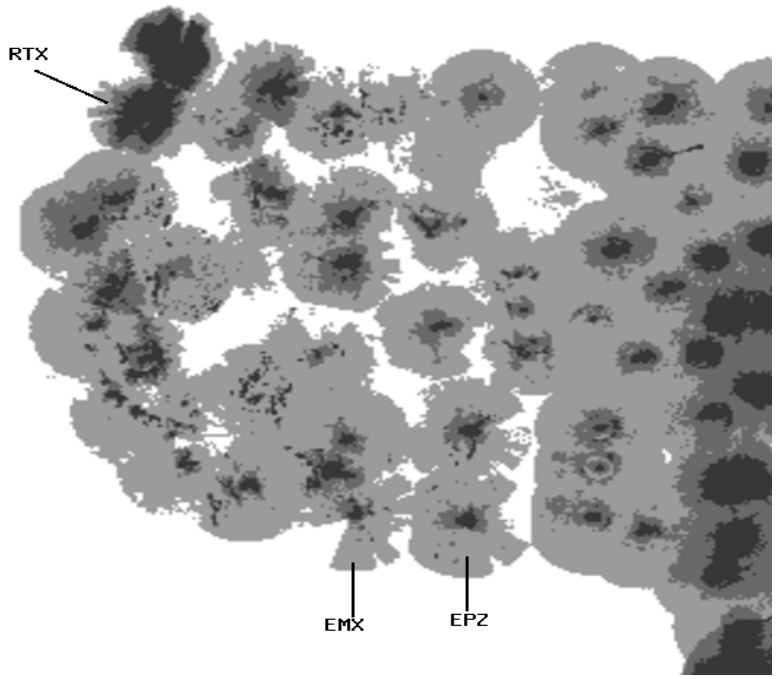

Figure 3. Relative frequencies of radar echoes > 15 dBZ, from unedited RCM mosaics. The period covered is 1 October - 31 December 1997 and 1 September - 31 October 1998. Blank indicates < 1%, gray shades indicate 1-5%, 6-10%, and > 10% from lightest to darkest. Effects of terrain occultation are clearly evident near Portland, Oregon (RTX), Tuscon, Arizona (EMX), and El Paso, Texas (EPZ).